GEOMATICS ENGINEERING (Advanced Surveying)

Theodolite Surveying - Part I

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- It is an optical instrument used in Surveying.

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- **Purpose:**

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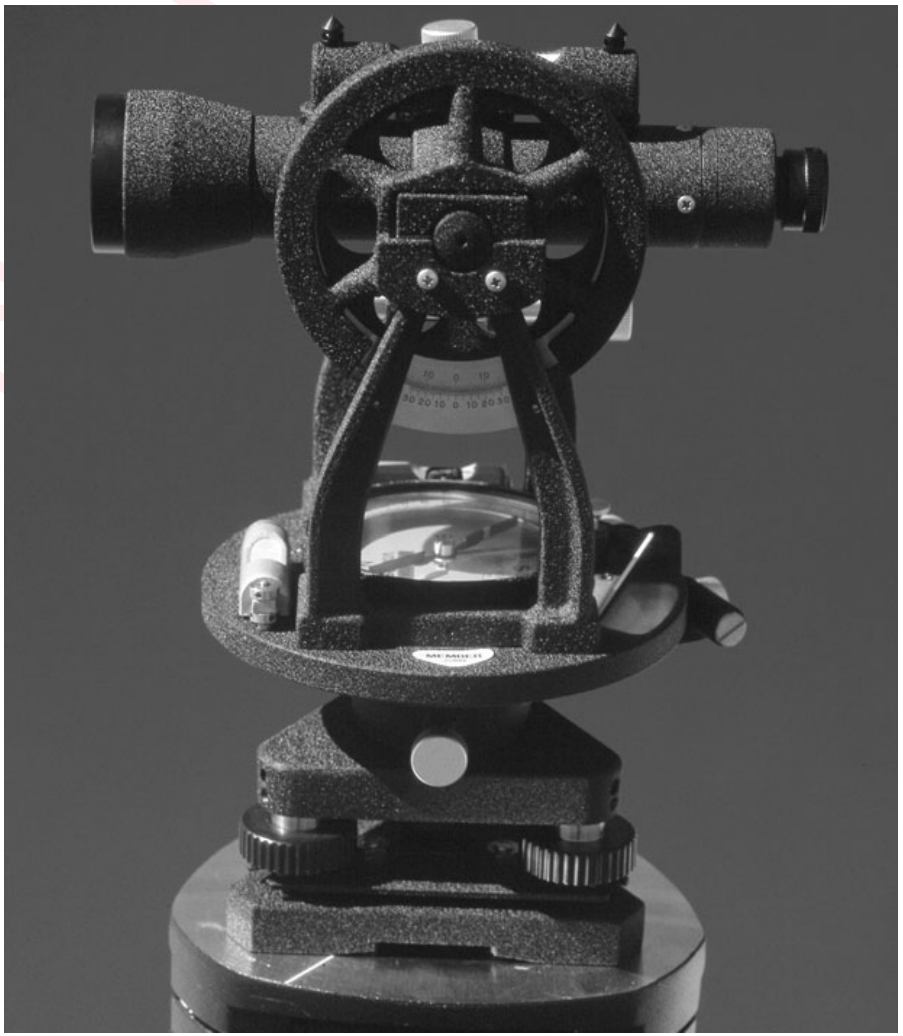
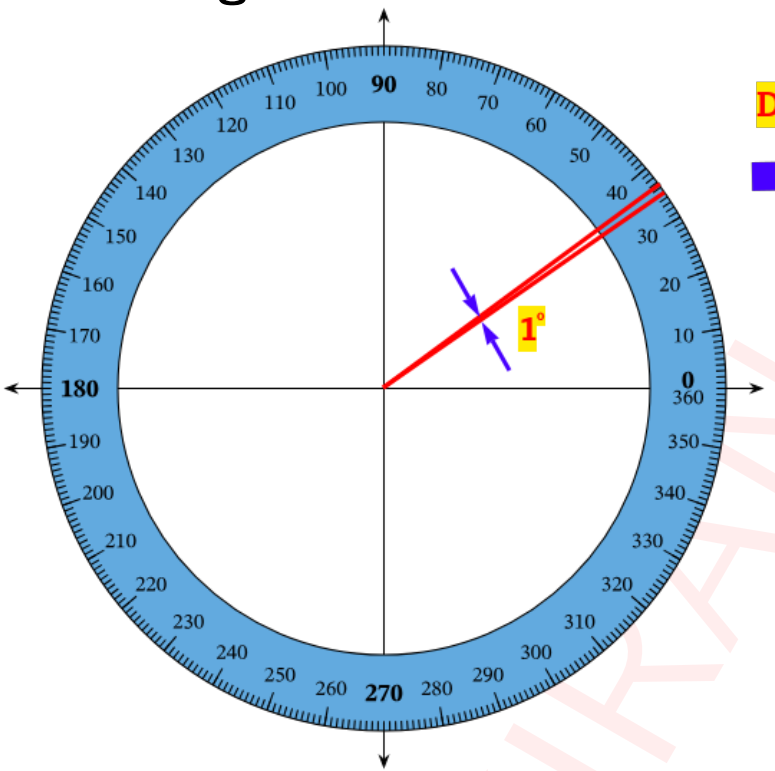
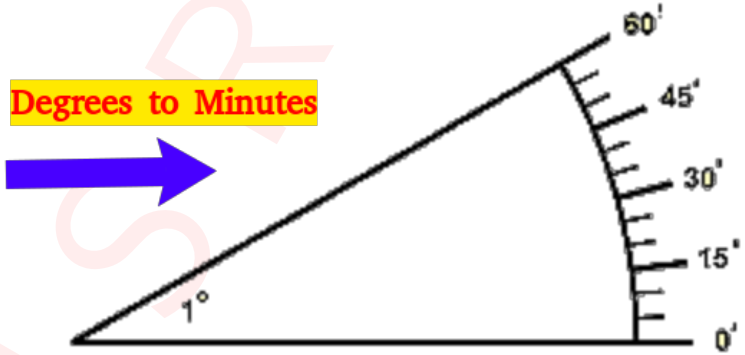
  Measurement of **Horizontal** as well as **Vertical angles**.
- **Unit of Measurement:**
  Degrees, Minutes and Seconds

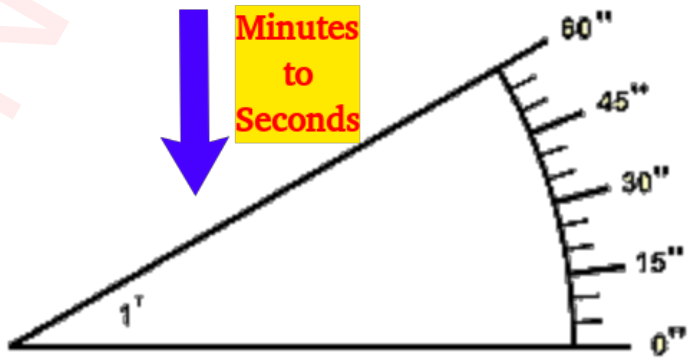


Introduction

Units for Angular Measurement:





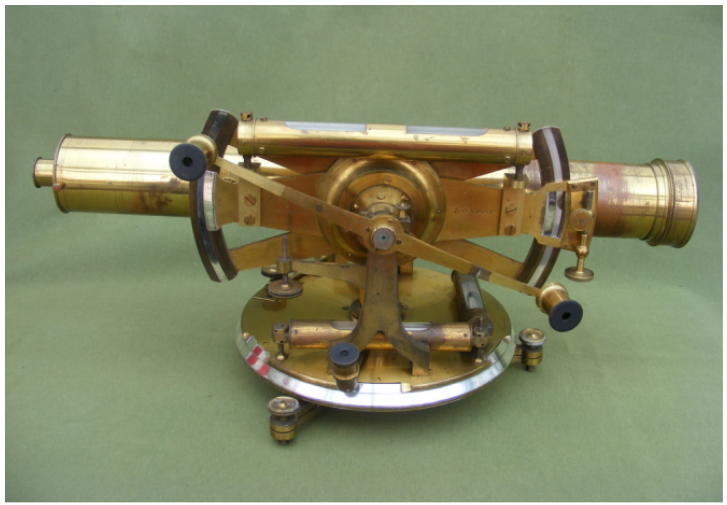


Conversion of Units

- **Degrees (^{0}):** $1^0 = \frac{\pi}{180}$ radians
- **Minutes (') :** $1' = \frac{1^0}{60}$
- **Seconds ("):** $1'' = \frac{1'}{60}$

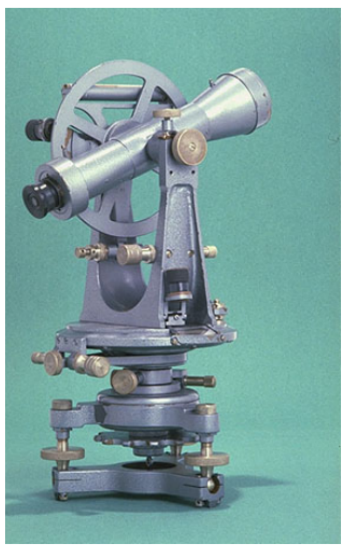
Introduction

Evolution of Theodolites:



Everest Theodolite

Plain Theodolite



Transit Vernier Theodolite

Repeating Theodolite

Directional Theodolite

Electronic Theodolite

Introduction

Classification of Theodolites:

- Based on the degree of freedom of Telescope in the vertical plane
  1. **Transit Theodolite**
     Telescope can be rotated in a full circle about horizontal axis in the vertical plane.
  2. **Non-transit Theodolite**
     Telescope cannot be rotated in a full circle in the vertical plane.

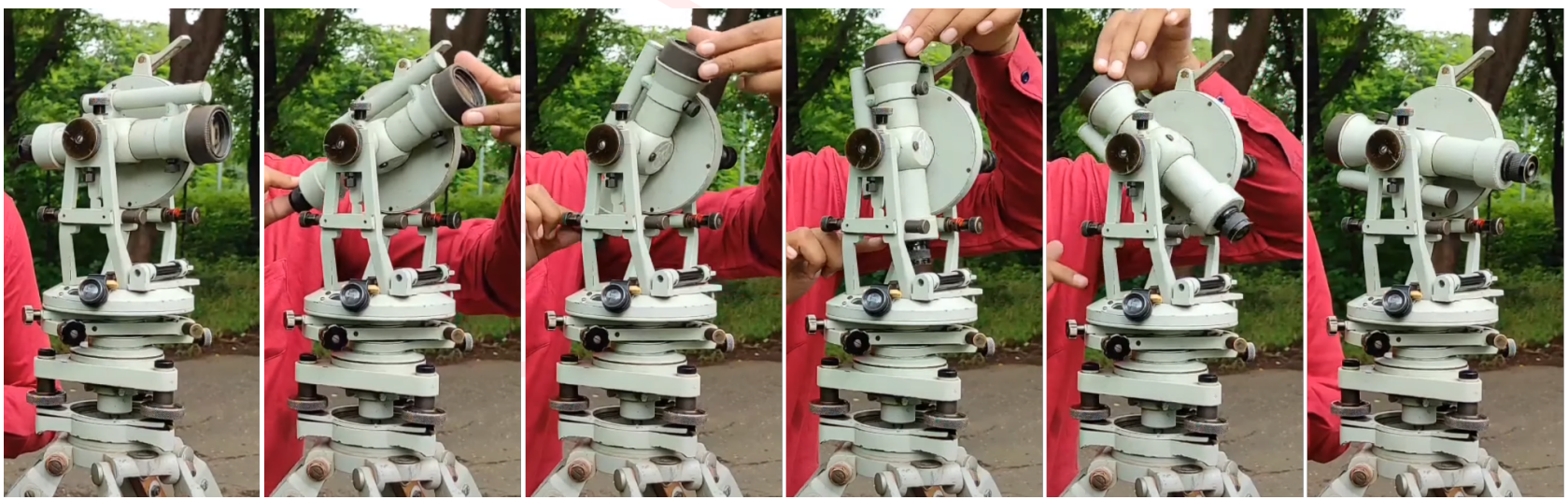
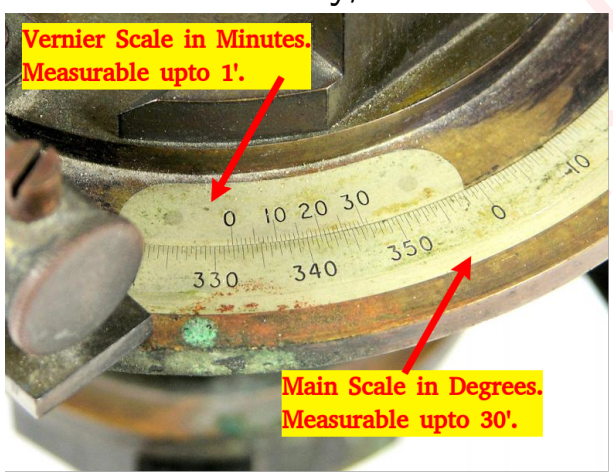


Figure: Transiting the Theodolite

Introduction

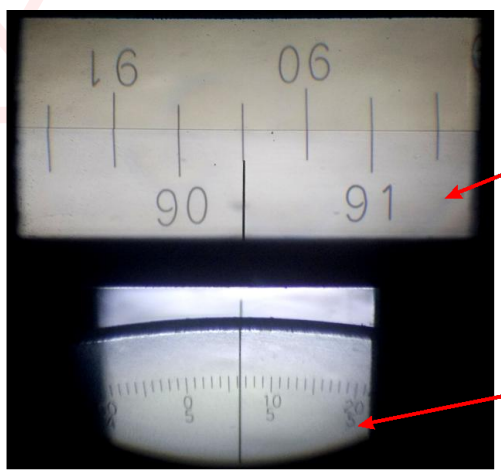
Classification of Theodolites:

- Based on the precision of Graduated circles (Horizontal & Vertical Circles).
  1. **Vernier Theodolite**
     - Graduated Circles use Verniers for angular measurements.
     - Generally, Least count = 20"
  2. **Micrometer Theodolite** or **Micro-optical Theodolite**
     - More precise than Vernier Theodolites.
     - Graduated circles use a micrometre and a direct-angle-reading-microscope.
     - Generally, Least count = 1".



Reading shown = 331 30'
+
24'
= 331 54'

VERNIER-TYPE GRADUATION



Reading shown = 90° 20'
+
5' 6"
= 90° 25' 6"

MICROMETER-TYPE GRADUATION

Introduction

Classification of Theodolites:

- Based on Measurement of Horizontal angles
  1. **Repeating Theodolite**
     - It has 2 vertical axes (similar to double-spindle arrangement of Transit Theodolites).
     - It measures a horizontal angle by repeated observation of angles at different settings on the horizontal circle, and then dividing the total angle by the number of observations.
     - Horizontal and vertical circles can be viewed and read simultaneously through the reading microscope.
  2. **Directional Theodolite**
     - It has 1 vertical axis only ∴ Horizontal circle is fixed.
     - It measures directions, instead of angles. Hence, an angle between the lines can be found by subtracting the first direction from the second.
     - Each observation shall be the mean of readings on diametrically opposite sides of the circle (similar to A & B verniers of Transit Theodolites).

Introduction

Classification of Theodolites:

- Based on Construction
  1. **Optical-Mechanical Theodolite**
     - Observations are taken manually by reading from Graduated circles.
     - All operations for setting and orientation are manual.
  2. **Electronic-Digital Theodolite**
     - Provides the value of observation directly on the digital viewing panel.
     - Comprises a mechanism for automatic instrument orientation.
     - Consist of a Electronic Data collectors, Keyboard and Digital Panel.
     - Can be interfaced with Computers for data transfer.

Introduction

Classification of Theodolites:

In this course, we shall confine our discussions to

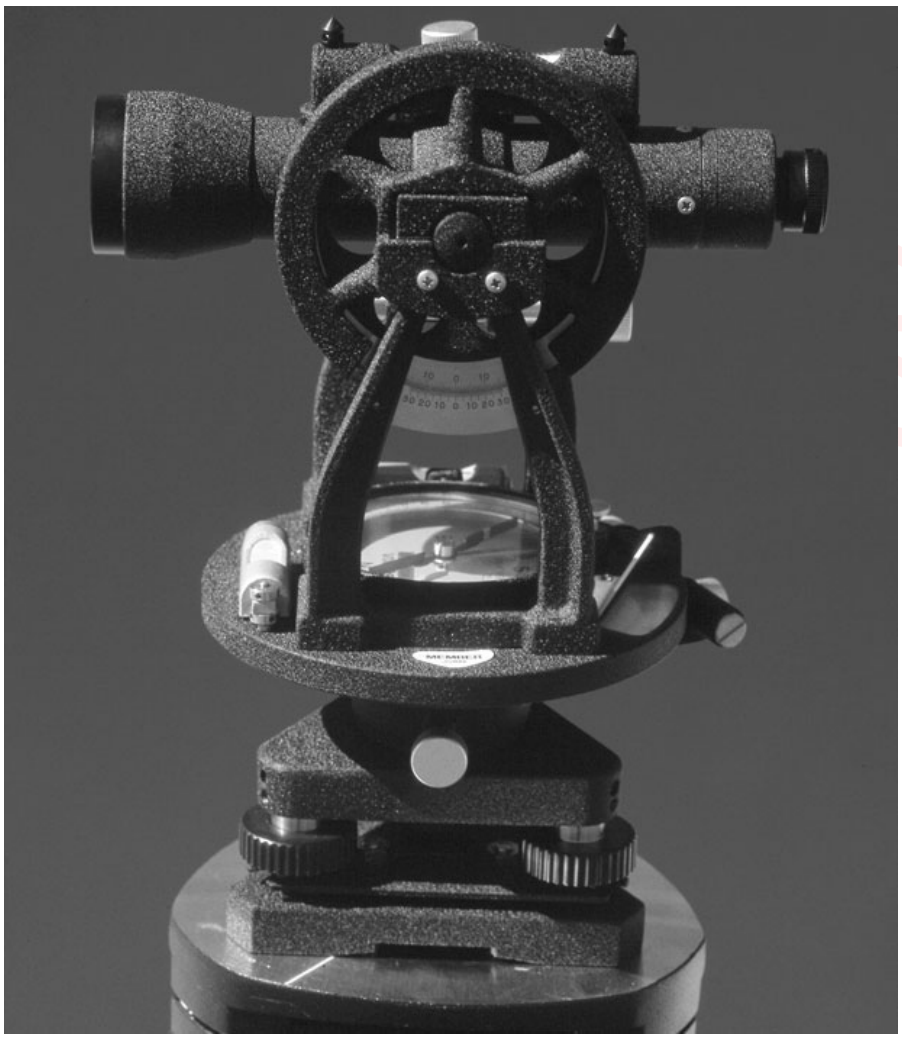
Transit-Vernier Theodolites

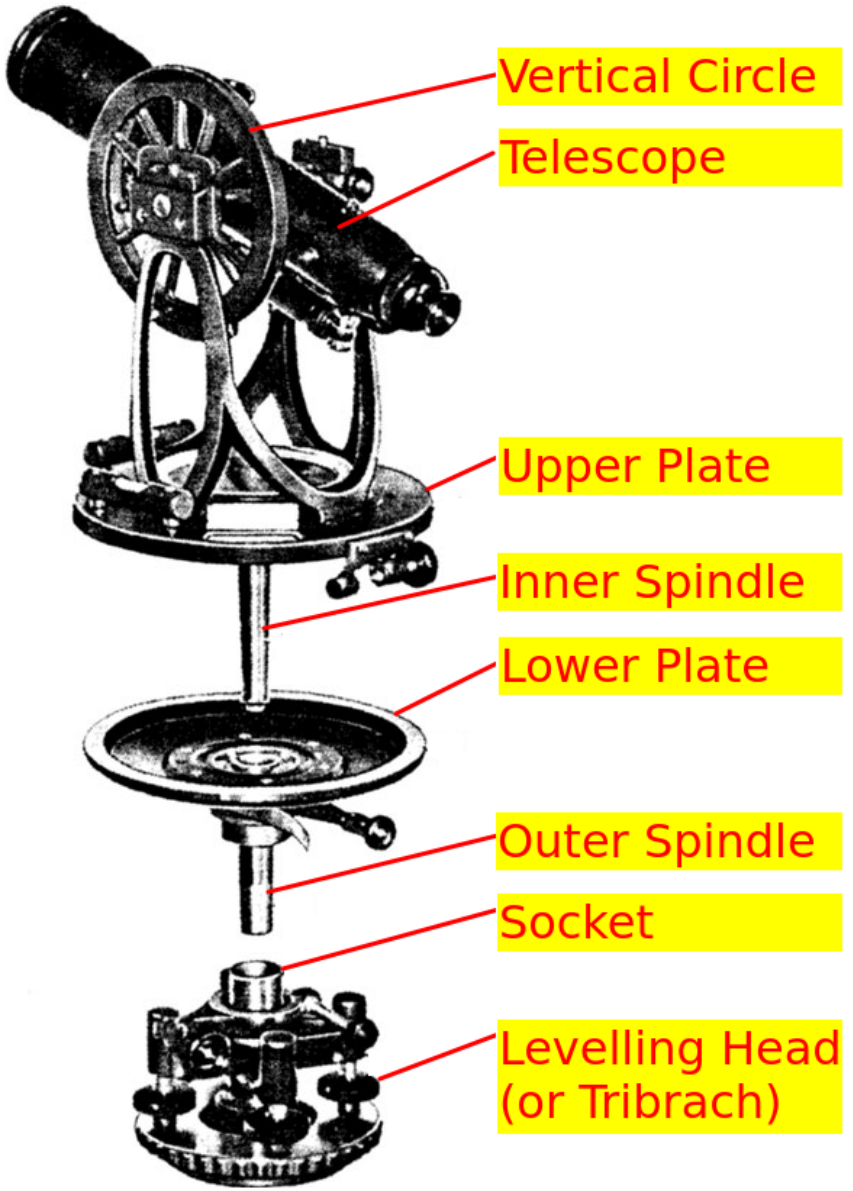
and

Electronic Theodolites

Transit-Vernier Theodolites

Parts of a Transit-Vernier Theodolite:

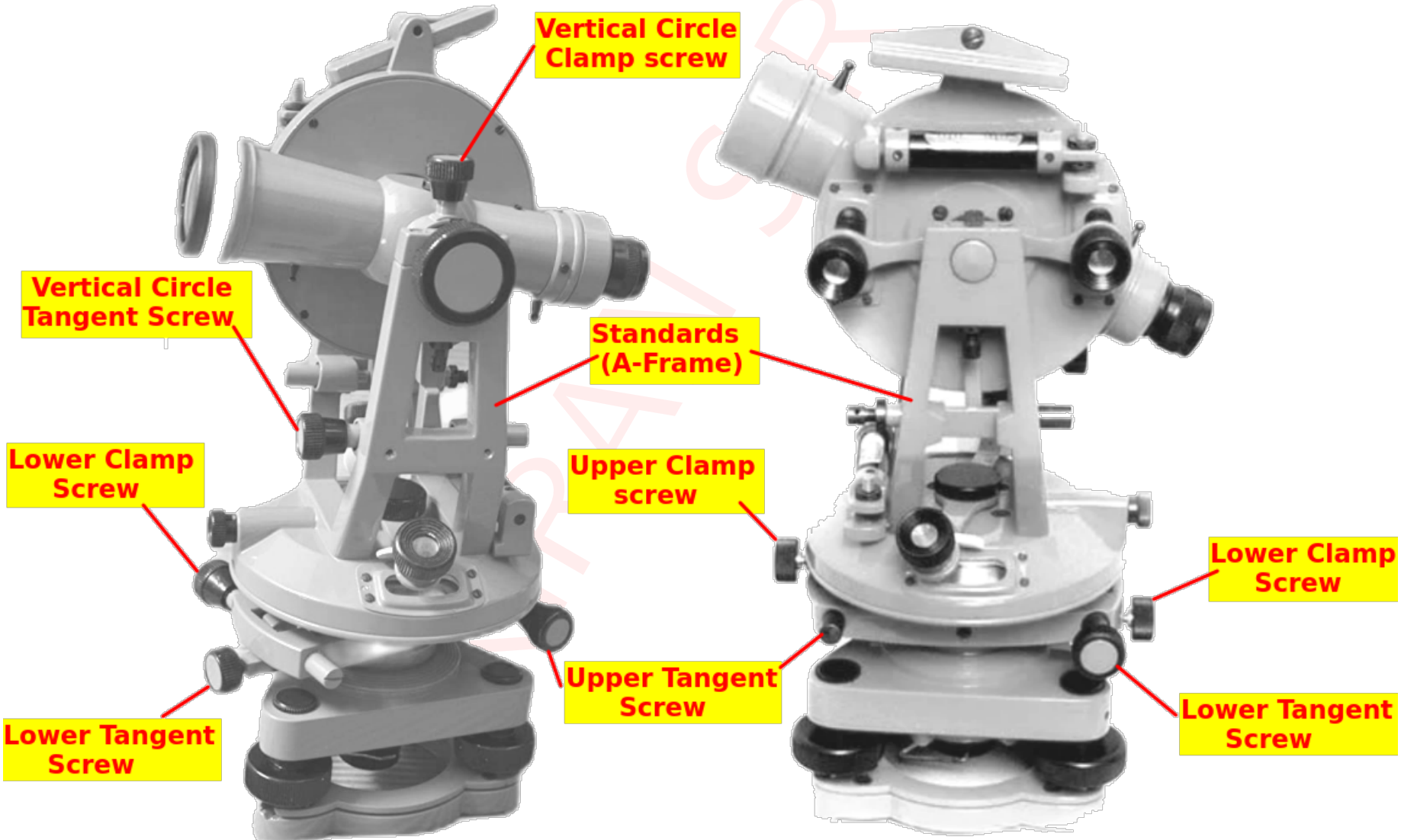




A theodolite with its primary components disassembled

Transit-Vernier Theodolites

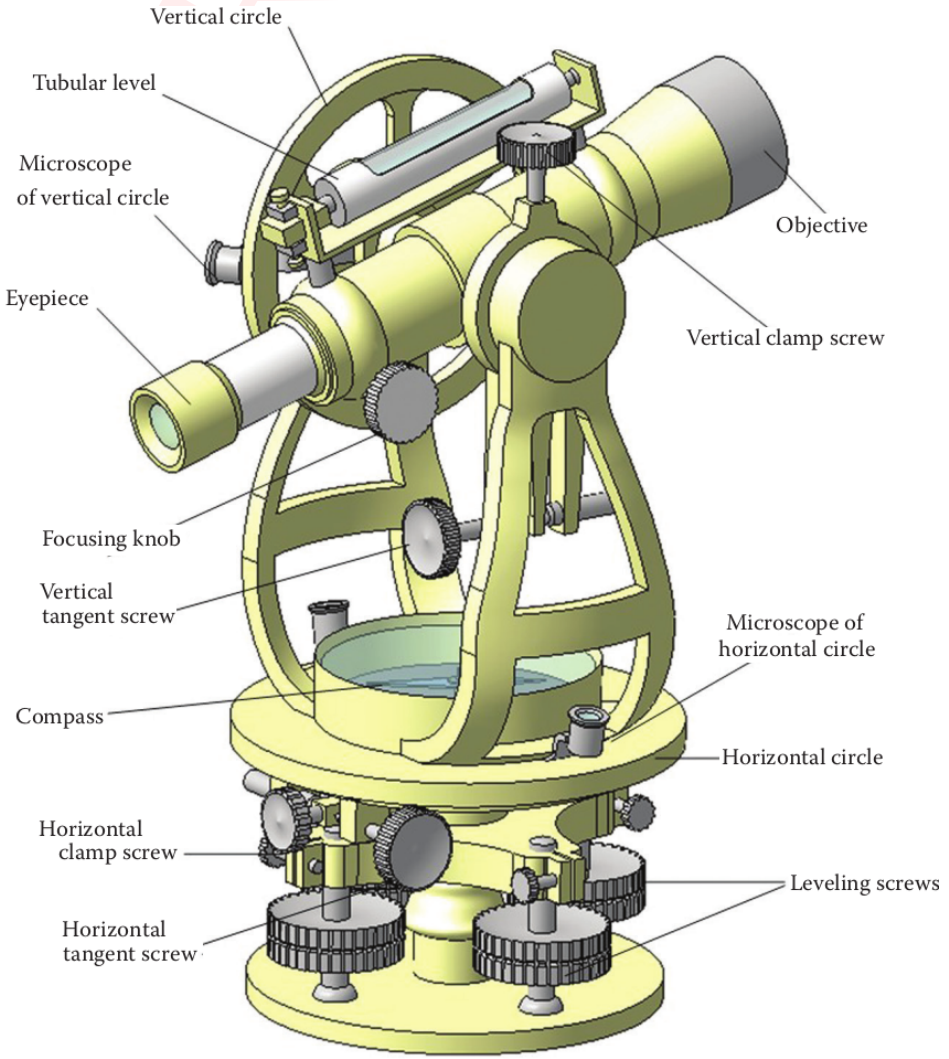
Parts of a Transit-Vernier Theodolite:



Transit-Vernier Theodolites

Parts of a Transit-Vernier Theodolite:

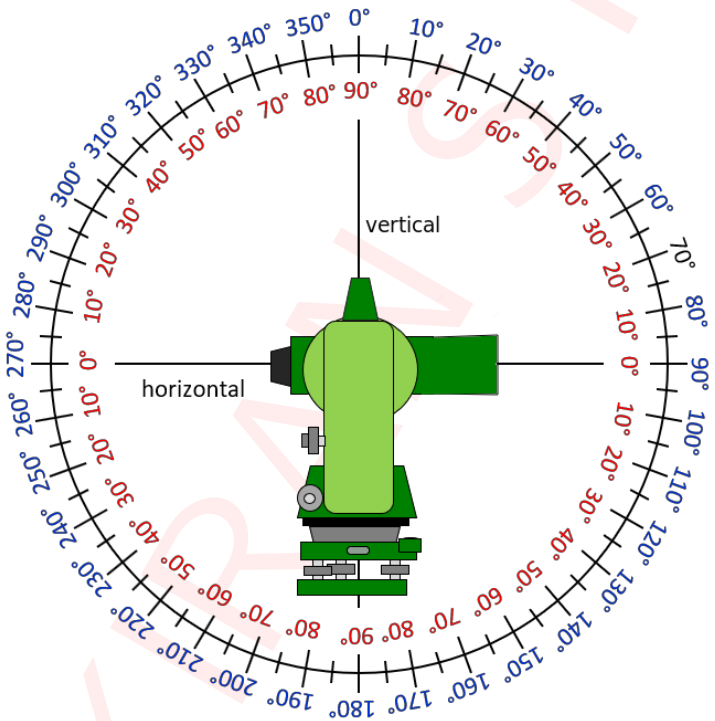
1. **Telescope:**
   - Used to sight the object.
   - Consists of eye-piece, object glass and focusing screw.
   - Mounted on horizontal axis.
2. **Vertical Circle:**
   - Used to measure vertical angles.
   - Rigidly attached to telescope (i.e., it rotates with the telescope).
   - Graduated, either from 0-360^0 or divided into 4 quadrants (measuring 0 – 90^0).



Transit-Vernier Theodolites

Vertical Circle:

- The two kinds of graduating the vertical circles is shown here.

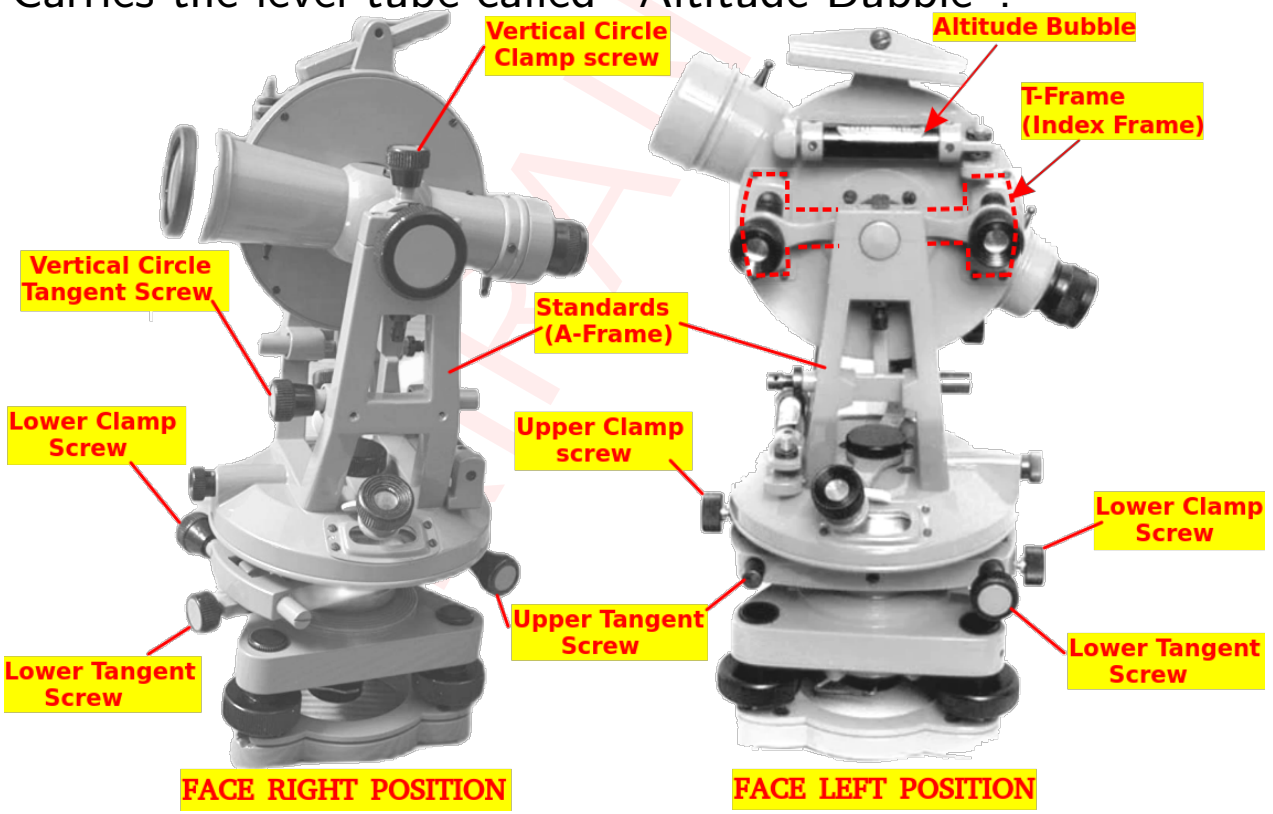


- Red is known as (Vertical angle circle).
- Blue is known as (Zenith angle circle).
- This figure helps understand how the two types of angles relate to each other.

Transit-Vernier Theodolites

Parts of a Transit-Vernier Theodolite:

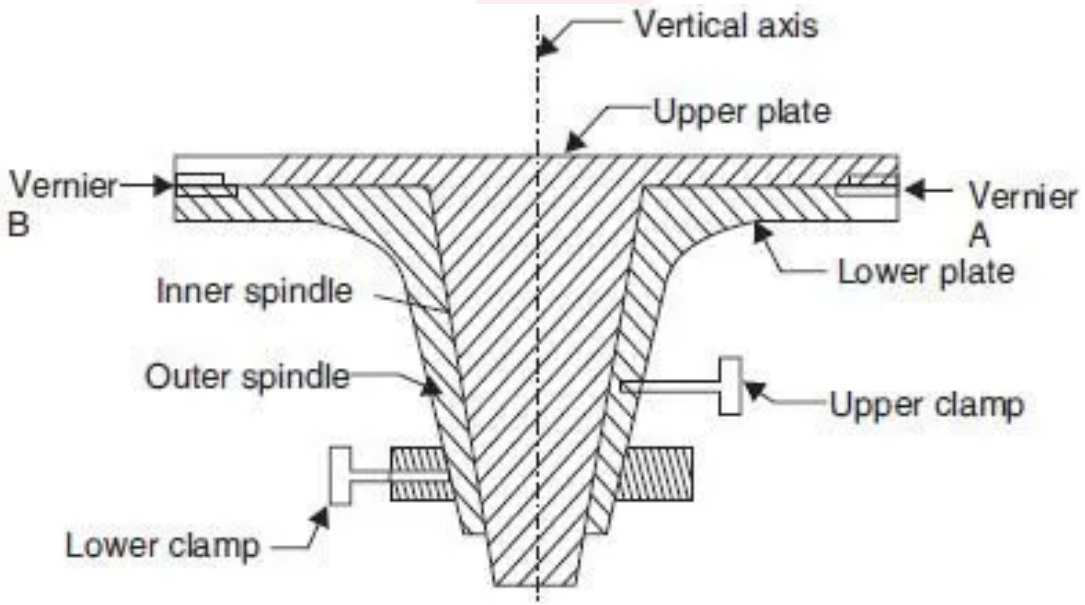
3. **A-Frame (Standards):**
   - Supports Horizontal axis of the telescope.
   - Supports T-frame (or Index Frame) and vertical circle clamp.
4. **Index frame (T-Frame or Vernier Frame):**
   - Supports the vernier on the vertical circle.
   - Carries the level tube called "Altitude Bubble".



Transit-Vernier Theodolites

Parts of a Transit-Vernier Theodolite:

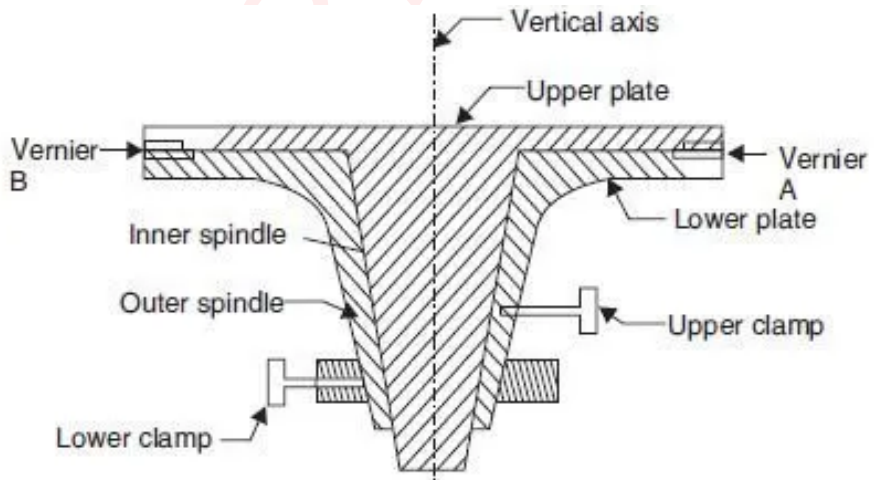
5. **Spindles:**
   - conical arrangements to which upper & lower plates are separately fixed.
   - Inner spindle $\Longrightarrow$ carries upper plate (carries verniers).
   - Outer spindle $\Longrightarrow$ carries lower plate (carries main circular scale).



Transit-Vernier Theodolites

Parts of a Transit-Vernier Theodolite:

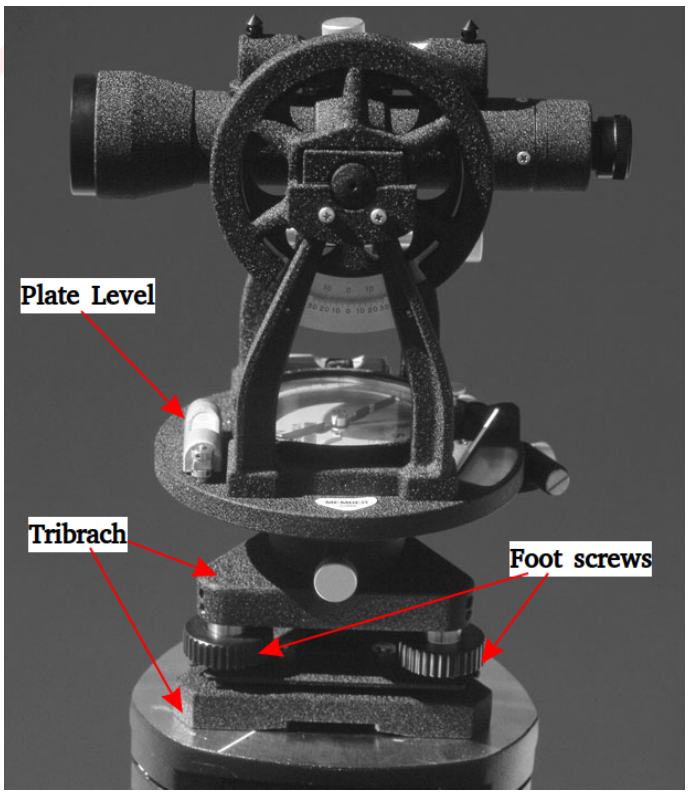
6. **Lower Plate:**
   - Attached to outer spindle.
   - Carries main circular scale for horizontal angle measurements. Therefore, lower plate is also called Scale plate.
   - Consists of lower clamp screw (for fixing) and tangent screw (for fine adjustment)
7. **Upper Plate:**
   - Carries two vernier scales at diametrically opposite points.
   - Supports A-Frame.
   - Consists an upper clamp screw and tangent screws.



Transit-Vernier Theodolites

Parts of a Transit-Vernier Theodolite:

8. **Levelling Head:**
   - Consists of two parallel triangular plates (called **Tribrach plates**) & three footscrews. Its uses are:
     - To support the main part of the instrument.
     - To attach the theodolite to the tripod.
     - To level the instrument.
9. **Foot Screws:**
   - Used to level the instrument.
10. **Plate Levels:**
    - Fixed to upper plate and placed parallel to Horizontal axis.



Relevant Terminologies

1. **Swinging the Telescope:** means to rotate the telescope about its vertical axis in the horizontal plane. A swing is called right or left according as the telescope is rotated clockwise or counter clockwise.
   - If the telescope is rotated clockwise $\Longrightarrow$ Right swing
   - If the telescope is rotated anticlockwise $\Longrightarrow$ Left swing

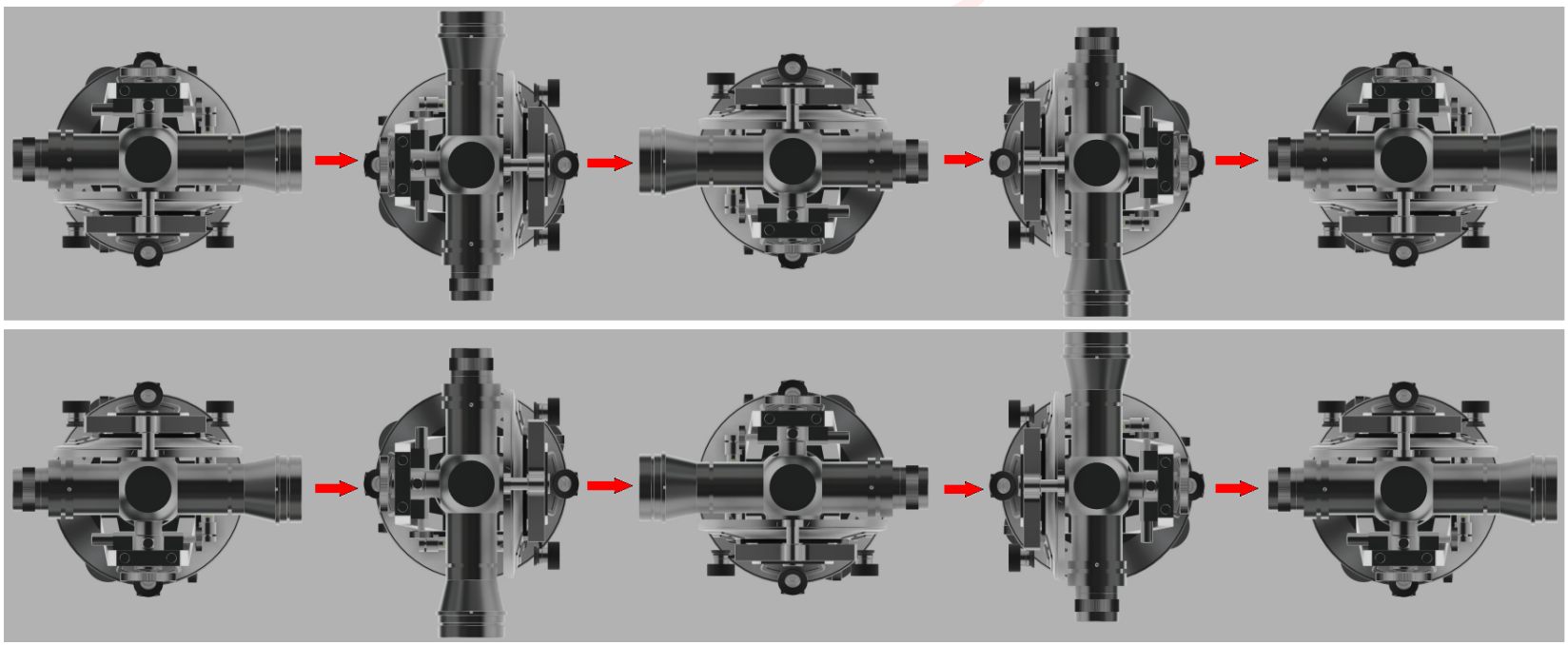


Figure: Swinging the Telescope (Plan View)

Relevant Terminologies

2. **Transiting the theodolite:** means rotating the telescope in the vertical plane, through 180^o. Since Line of sight is reversed in this operation, it is also called **"Reversing"** or **"Plunging"**.

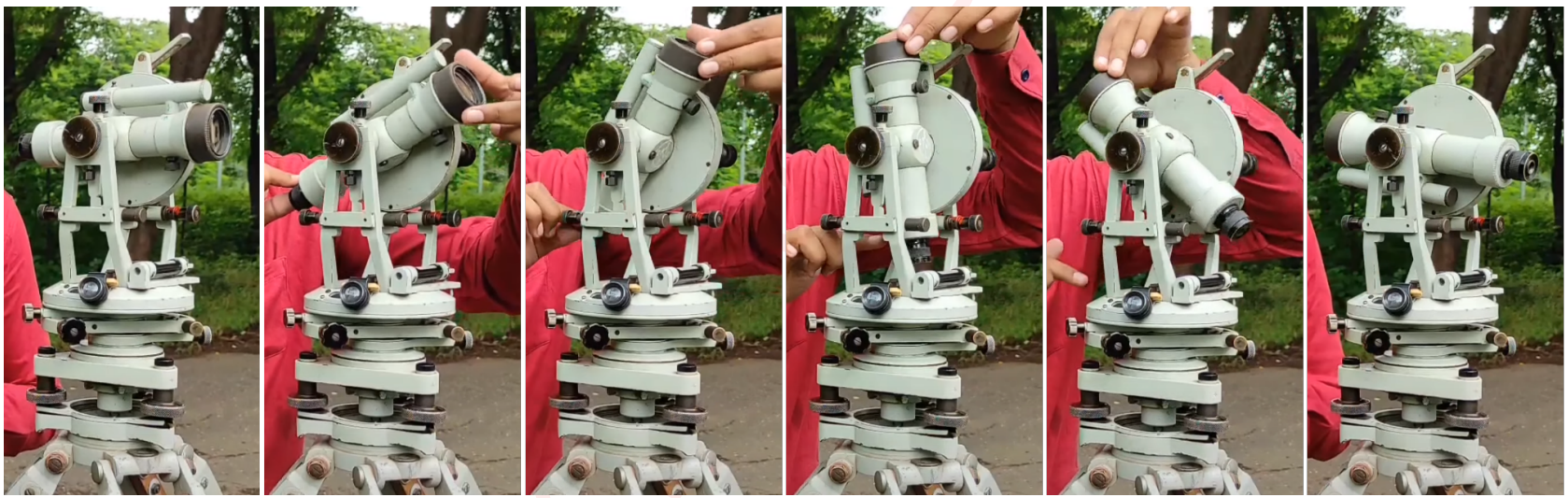
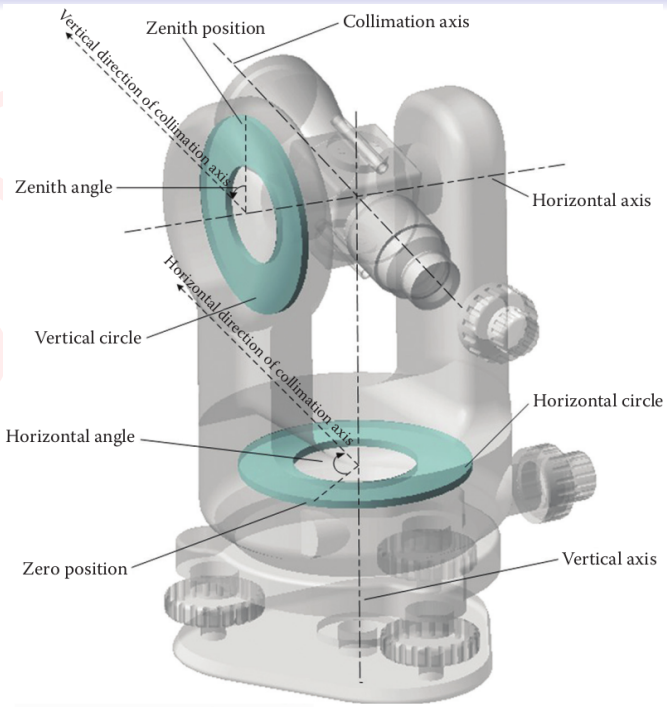
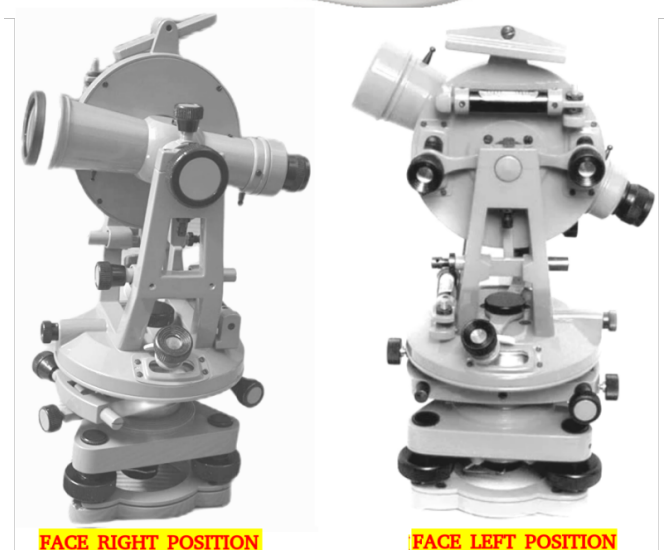


Figure: Transiting the Telescope (Side View)

Relevant Terminologies

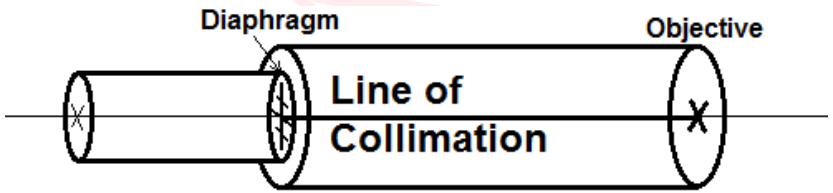
3. **Horizontal axis (Trunnion axis):** is the axis about which the telescope transits.
4. **Vertical axis:** is the axis about which upper & lower plates rotate.
5. **Face Left:** If face of the vertical circle is to the left side of observer, then such observation of the angles is known as face left observation.
6. **Face Right:** If the face of the vertical circle is to the right side of observer, then such observation of the angles is known as face right observation.



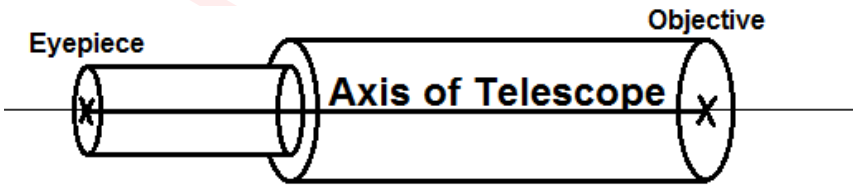


Relevant Terminologies

7. **Changing Face:** is an operation of bringing the face of the telescope from left to right and vice-versa.
8. **Axis of level tube (Bubble line):** is the line drawn tangential to the longitudinal curve of the level tube, at the centre of the bubble. If the bubble is central, then the axis of the level tube is horizontal.
9. **Line of Sight (LOS)** or **Line of Collimation (LOC):** passes through the optic center of objective lens and intersection of crosshairs of the diaphragm.

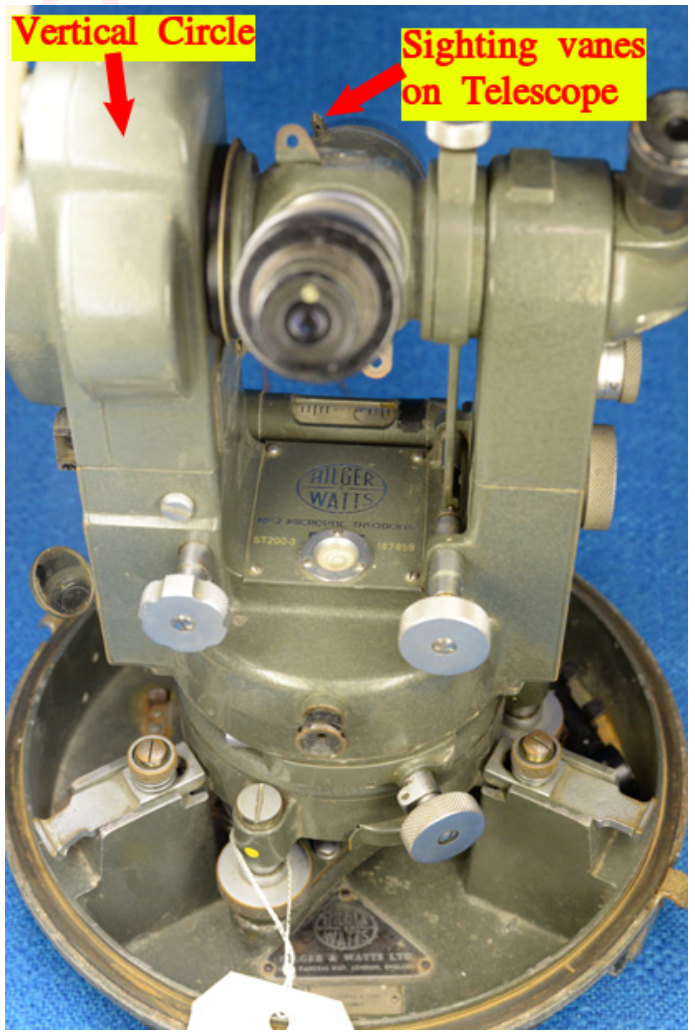


10. **Axis of the Telescope:** is an imaginary line joining the optical center of the objective lens to the optical center of the eyepiece.



Relevant Terminologies

11. **Telescope normal:** when
    - the face of vertical circle is to the left of observer, and
    - sighting vane or the bubble of telescope is above the telescope.
12. **Telescope inverted:** when
    - the face of vertical circle is to the right of observer, and
    - sighting vane or the bubble of telescope is below the telescope.

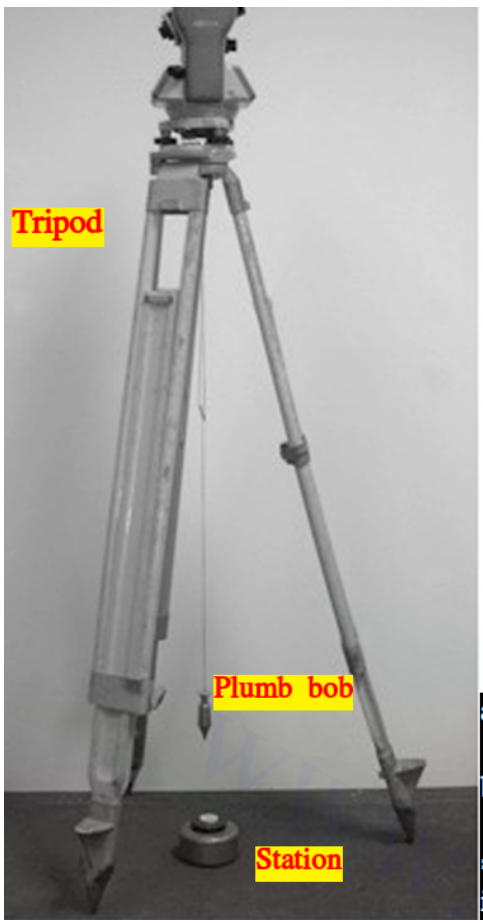


Temporary Adjustments of a Theodolite

- These are a set of operations which are performed on a theodolite to make it ready for taking observations.
- The adjustments to be made at every setting of the instrument.
- It includes the following steps:
  1. Setting up the theodolite over a station.
  2. Leveling up.
  3. Elimination of parallax.

Temporary Adjustments of a Theodolite

1. **Setting Up:** It includes two operations:
   - Centering a theodolite over a station: Done by means of a plumb bob.
   - Approximately leveling it by tripod legs only: Done by moving tripod legs radially or circumferentially.



RADIAL MOVEMENT OF LEG

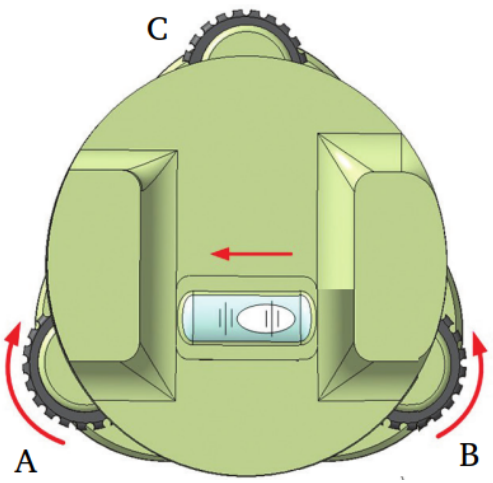
a) Shifts the plumb bob radially in the direction of the leg.
b) Does not affect the level status of the instrument appreciably.
=> This operation enables to centre the instrument over the given station point.

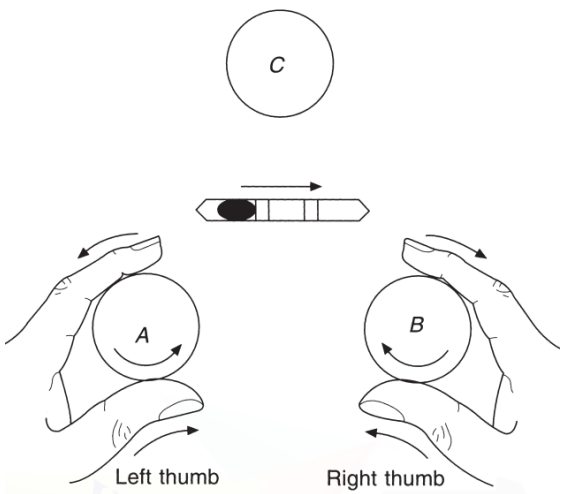
CIRCUMFERENCIAL MOVEMENT OF LEG

a) Does not appreciably shift the plumb.
b) Tilts the instrument and affects the level of the plate bubbles.
=> This operation enables approximate levelling of the instrument without shifting it off the station point.

Temporary Adjustments of a Theodolite

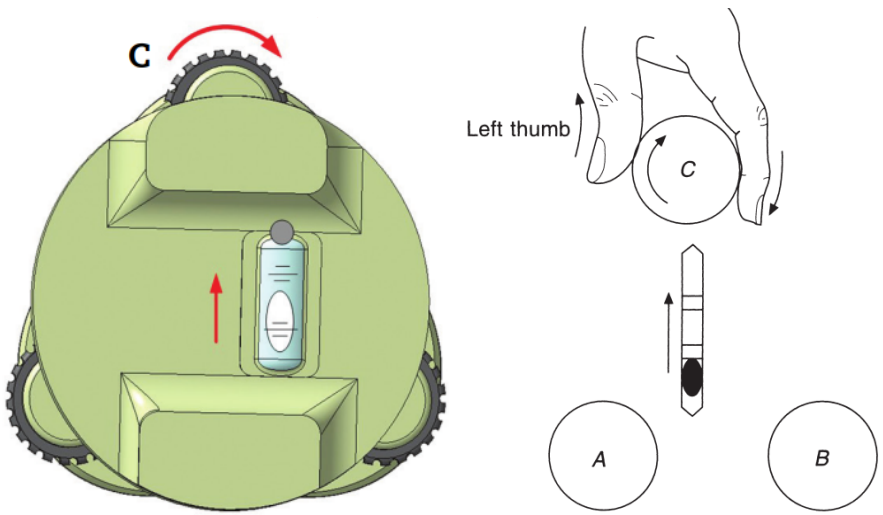
2. **Leveling Up:** Here, accurate leveling is performed with the help of foot screws with reference to the plate levels, so that the vertical axis shall be truly vertical. Procedure is as follows:
   - Turn the upper plate until the longitudinal axis of the plate level is roughly parallel to a line joining any two of the leveling screws (A & B).
   - Hold these two leveling screws between the thumb and first finger of each hand uniformly so that the thumb moves either towards each other or away from each other until the bubble comes to the center.





Temporary Adjustments of a Theodolite

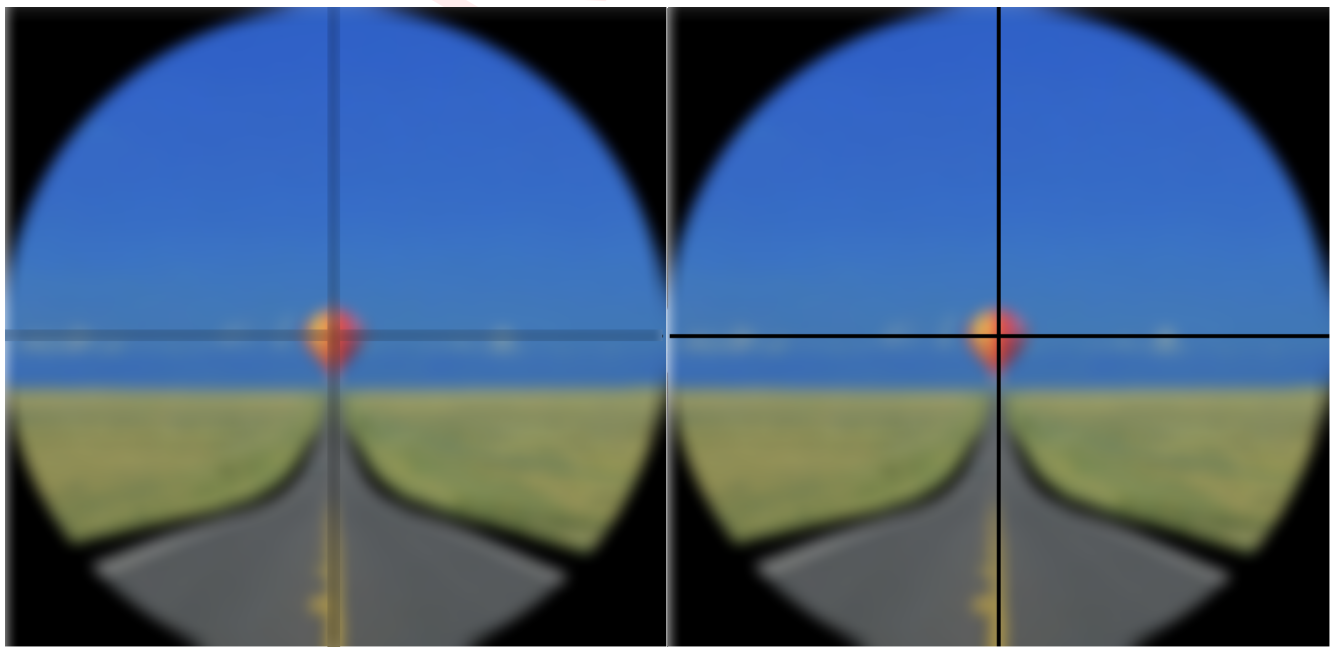
2. **Leveling Up (Procedure Contd...):**
   - Turn the upper plate through 90^0, i.e., until the axes of the level passes over the position of the third leveling screw 'C'.
   - Turn this leveling screw until the bubble comes to the center.



   - Repeat the above steps until the bubble is central in both the positions.

Temporary Adjustments of a Theodolite

3. **Elimination Of Parallax:**
   - Parallax is a condition arising when the image formed by the objective is not in the plane of the cross hairs. Parallax can be eliminated in two steps.
     i. **Focussing the Eye-Piece:** Point the telescope to the sky or hold a piece of white paper in front of the telescope. Move the eyepiece in and out until a distant and sharp black image of the cross-hairs is seen.



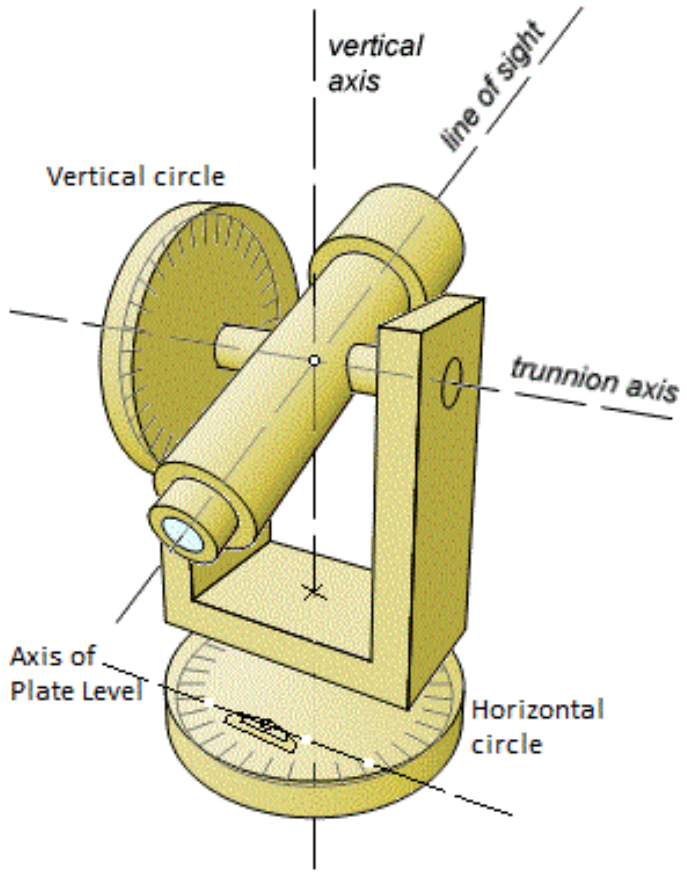
Temporary Adjustments of a Theodolite

3. **Elimination Of Parallax:**
   - Parallax is a condition arising when the image formed by the objective is not in the plane of the cross hairs. Parallax can be eliminated in two steps.
     ii. **Focussing the Object:** Telescope is now turned towards object to be sighted and the focusing screw is turned until image appears clear and sharp.

Permanent Adjustments of a Theodolite

What are Fundamental Lines of a Theodolite?

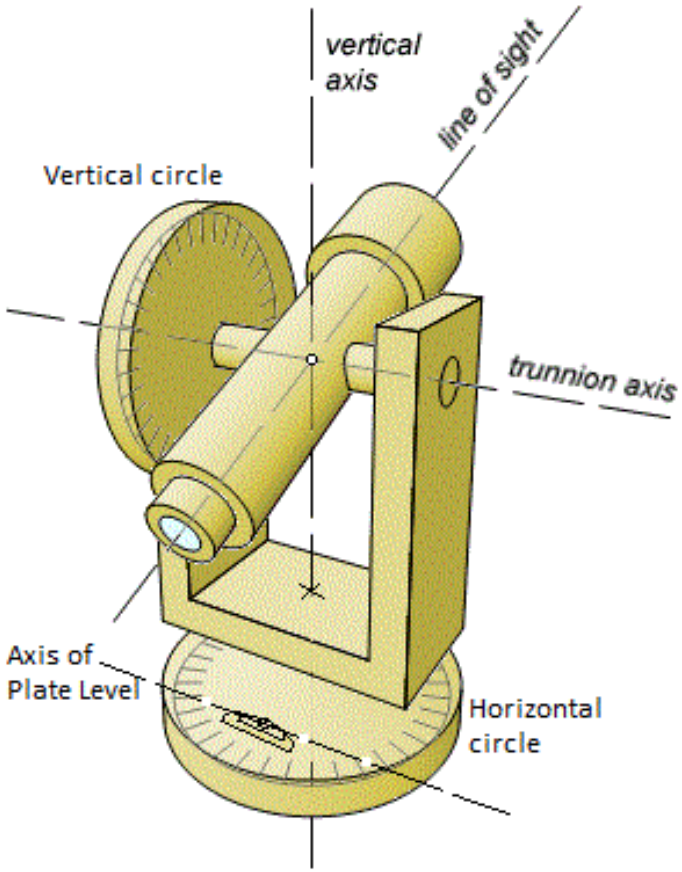
1. Horizontal axis (or Trunnion axis)
2. Vertical axis
3. Line of Sight (or Line of collimation)
4. Axis of plate level
5. Axis of altitude level



Permanent Adjustments of a Theodolite

Relationship between the Fundamental Lines of a Theodolite:
Theodolites shall necesarily fulfil the following relations.

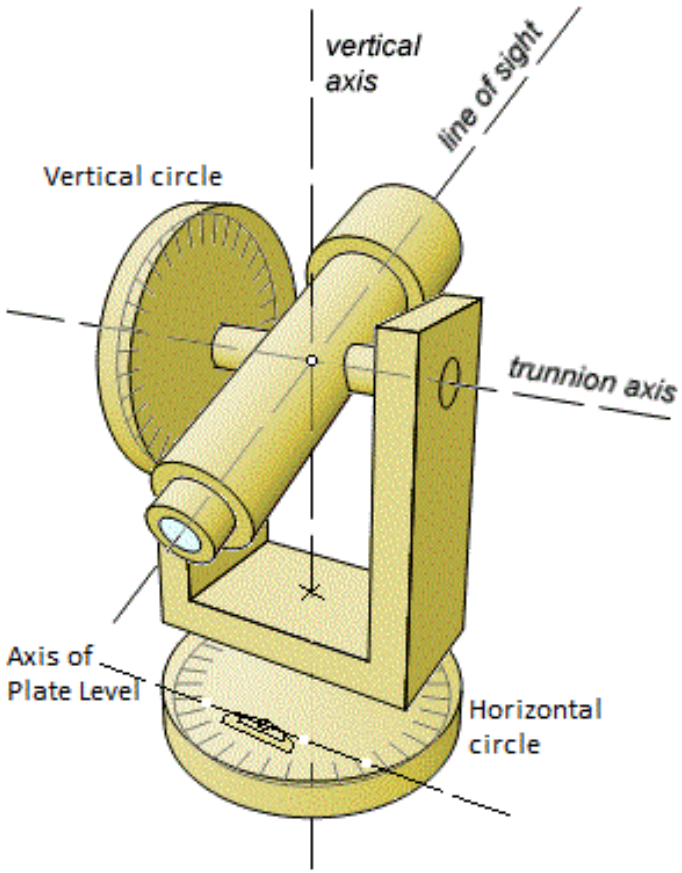
1. **Axis of plate level** must be perpendicular to **Vertical axis**.
2. **Line of Sight** must be perpendicular to **Horizontal axis**.
3. **Horizontal axis** must be perpendicular to **Vertical axis**.
4. **Axis of altitude level** must be parallel to **Line of Sight**.
5. **Vertical circle** reading must be zero, if **Line of Sight** is horizontal.



Permanent Adjustments of a Theodolite

Permanent Adjustments of a Theodolite:

- Permanent adjustments involve setting the essential parts of a Theodolite into their true positions relatively to each other. Such a theodolite, which obeys all the relations between fundamental lines, is said to be **"Perfectly Adjusted"**.
- **This is ensured as long as the relationship between fundamental lines of the Theodolite hold good**.
- Permanent adjustments of a Theodolite are done in the following order.
  1. Adjustment of plate level
  2. Adjustment of line of sight
  3. Adjustment of the horizontal axis
  4. Adjustment of altitude bubble and vertical index frame



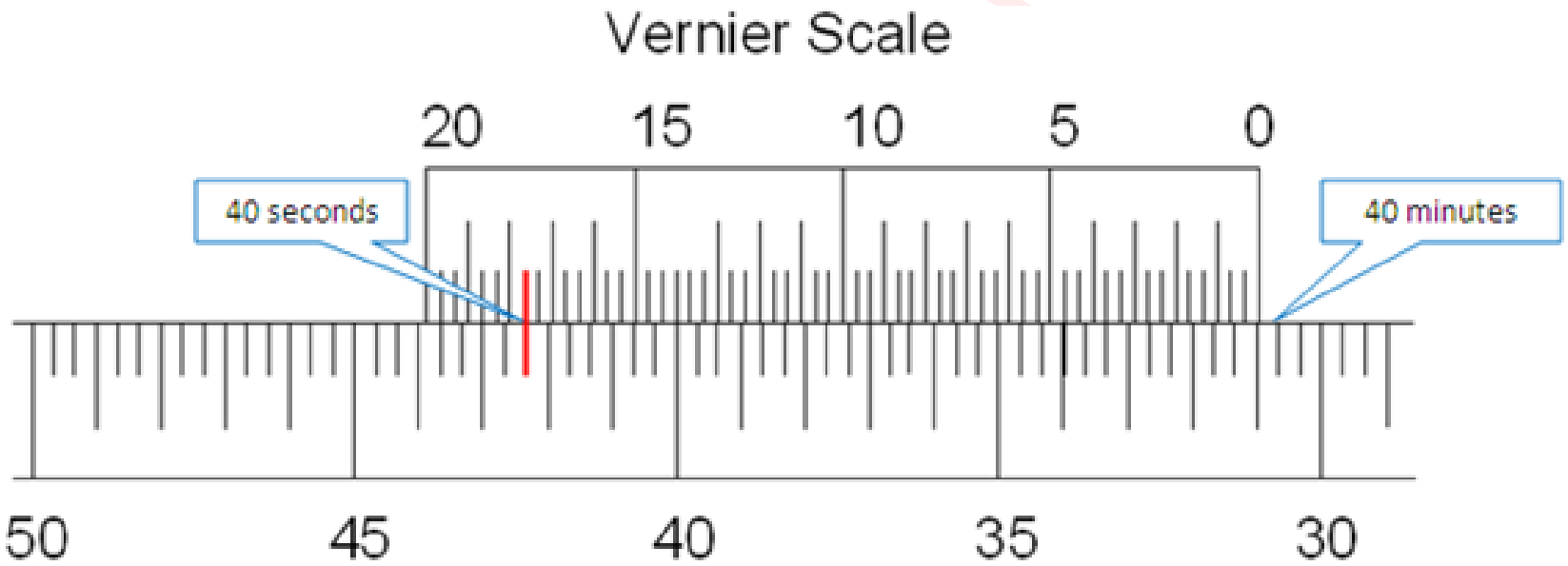
Permanent Adjustments of a Theodolite

The objective of Permanent Adjustments of a Theodolite:

1. **Adjustment of plate level** – to make vertical axis truly vertical. Thus, if the instrument is leveled up, the bubble of plate level becomes central.
2. **Adjustment of line of sight** – to place the intersecting point of horizontal and vertical crosshairs in the optical axis of the telescope. Thus, it requires adjustments of both horizontal & vertical crosshairs.
3. **Adjustment of the horizontal axis** – to make horizontal axis perpendicular to the vertical axis. Hence, the horizontal axis is truly horizontal when the instrument is leveled.
4. **Adjustment of altitude bubble and vertical index frame** – to make Line of Sight truly horizontal when the altitude bubble is central & vertical circle reading is zero.

How to read angles in a Transit-Vernier Theodolite?

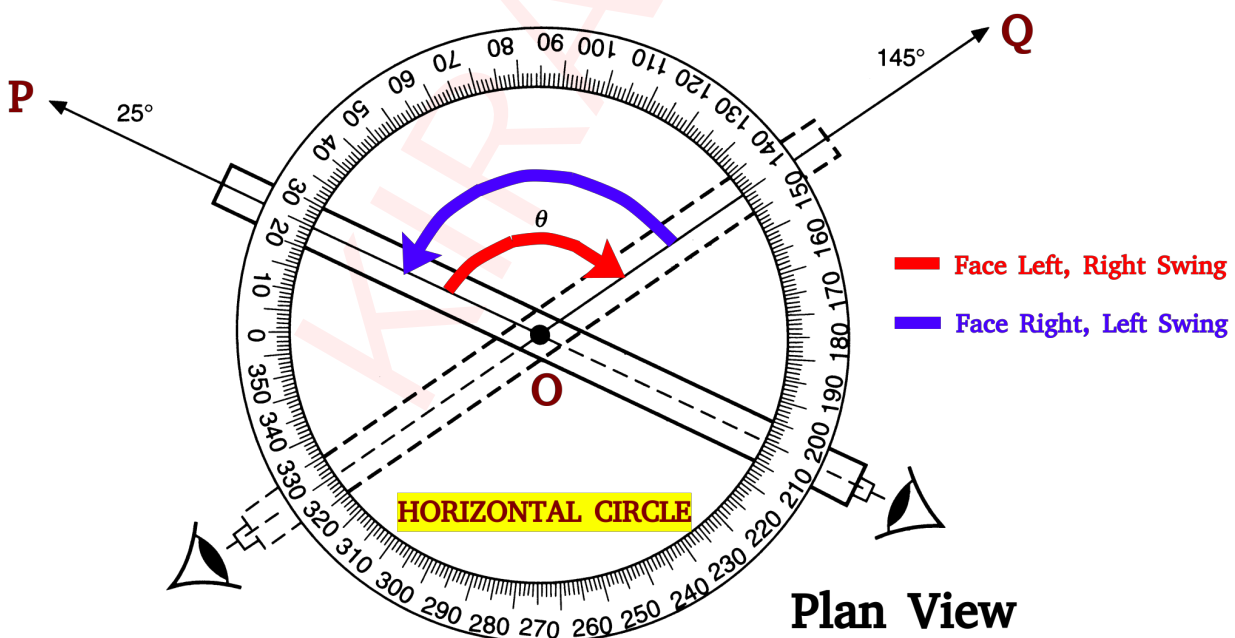
Angles are read from Horizontal and Vertical circles in the following manner:



	°	'	"
Main Scale	30	40	
Vernier Scale		17	40
Reading	**30**	**57**	**40**

Accurate measurement of Angles

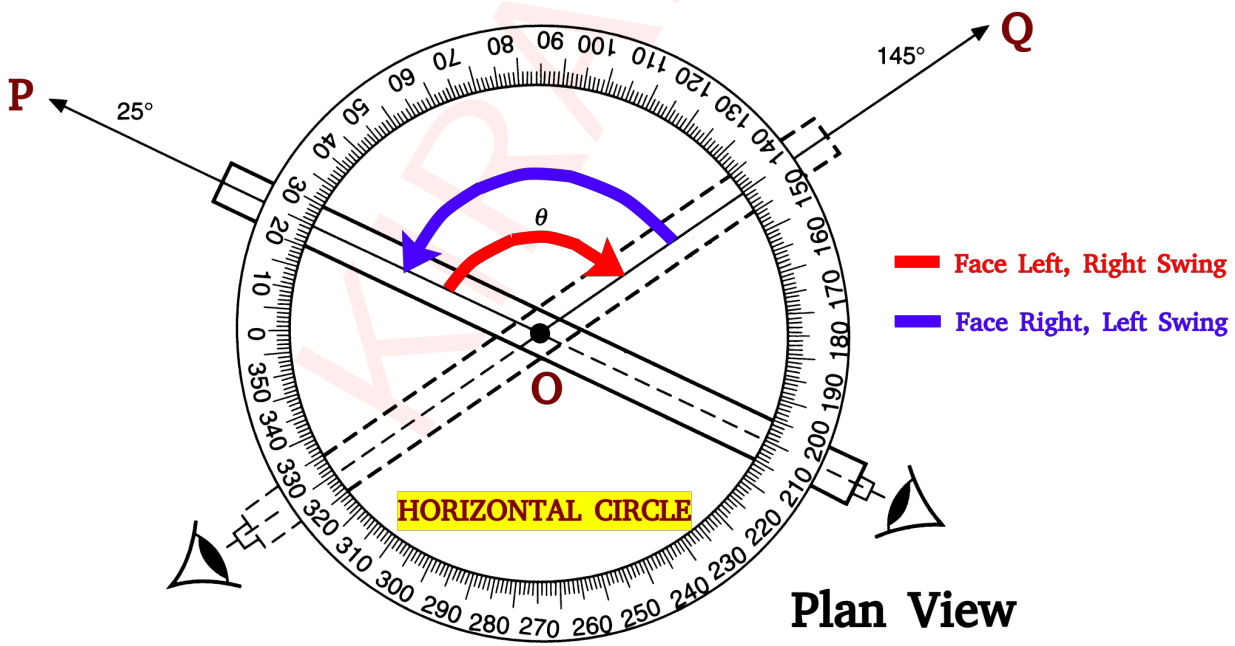
- Theodolites shall never perfectly obey the relations between its fundamental lines. Hence, Perfectly-adjusted Theodolites are hypothetical, and therefore, contribute to errors in measurement of angles.
- To eradicate such errors, an angle is measured in 2 modes using theodolite as:
  1. **Face Left, Right Swing mode**, AND
  2. **Face Right, Left Swing mode**.
- The average of the above modes give better results.



Plan View

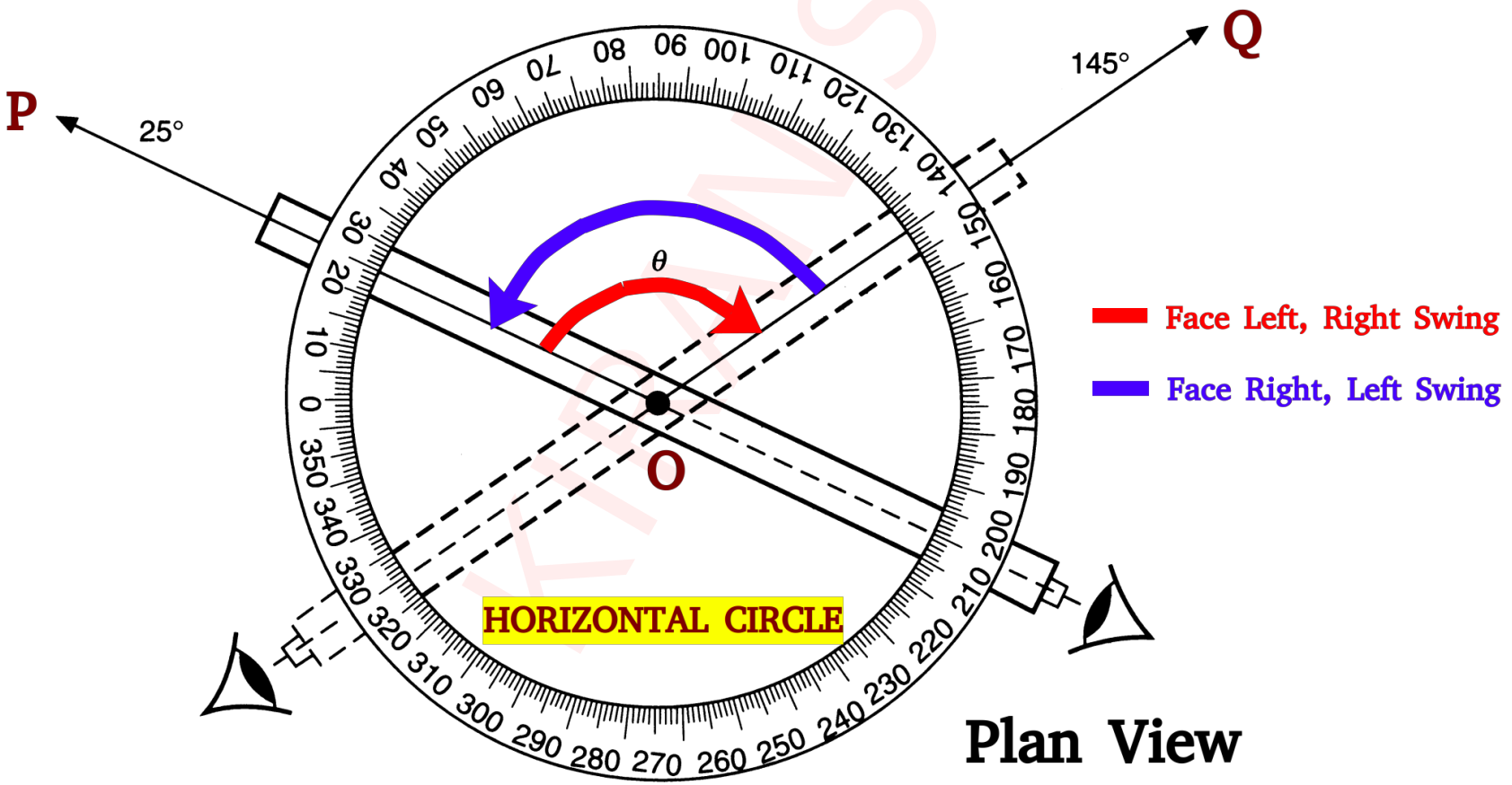
Accurate measurement of Angles

- To measure the included angle ∠POQ (see figure),
  1. The instrument set at point O sights point P first in **Face Left** position, which is then **swung Right** towards B and bisecting the same. Horizontal circle readings at P & Q are noted.
  2. The telescope is now transited to **Face Right** position. Without changing the angle, Q is sighted first and is then **swung Left** to bisect P. Horizontal circle readings noted again.
  3. Angles observed in both modes are averaged and then the included angle determined as = Reading at Q – Reading at P



Accurate measurement of Angles

- Note that,
  - In Right Swing, the reading on the Horizontal circle increases.
  - In Left Swing, the reading on the Horizontal circle decreases.



Applications of Theodolite

Theodolites have the following applications:

1. Measurement of Horizontal Angles
2. Measurement of Magnetic Bearing of a Line
3. Prolongation of a straight line
4. Measurement of Deflection Angles

Applications of Theodolite

(i) Measurement of Horizontal Angles: Horizontal angle is measured by any of the following two methods.

1. Repetition Method
2. Reiteration Method

Applications of Theodolite

(i) Measurement of Horizontal Angles:

1. Repetition Method
   - used for measurement of horizontal angles with high accuracy.
   - here, the same angle is measured repeatedly and averaged.
   - Generally, an angle is measured 3 times in Telescope normal condition and 3 times in Telescope inverted condition.

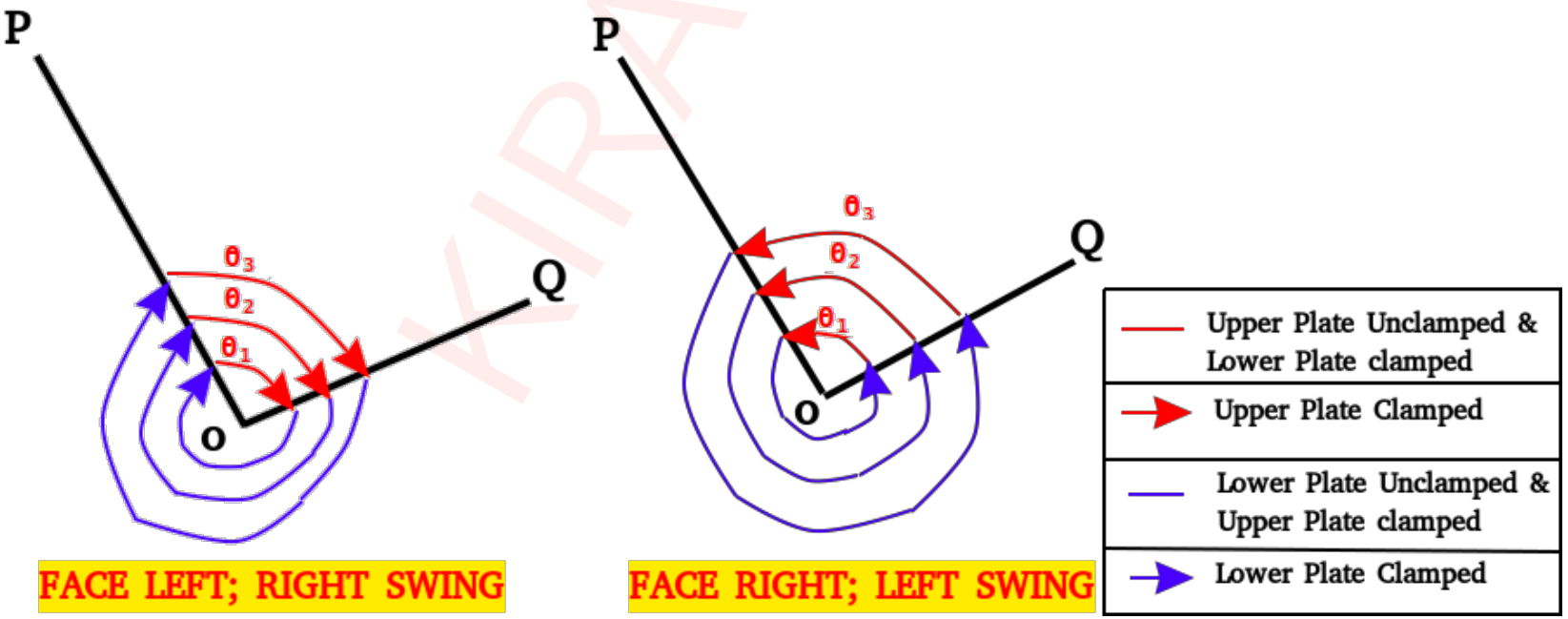
Applications of Theodolite

(i) Measurement of Horizontal Angles:

1. Repetition Method

Procedure:

- Set up the instrument over 'O' and level it accurately.
- With the help of upper clamp and tangent screw, set 0^0 reading on vernier 'A'. Note the reading of vernier 'B'.
- At Face Left, release the lower clamp and direct the telescope approximately towards the point 'P'. Tighten the lower clamp and bisect point 'P' accurately by lower tangent screw.



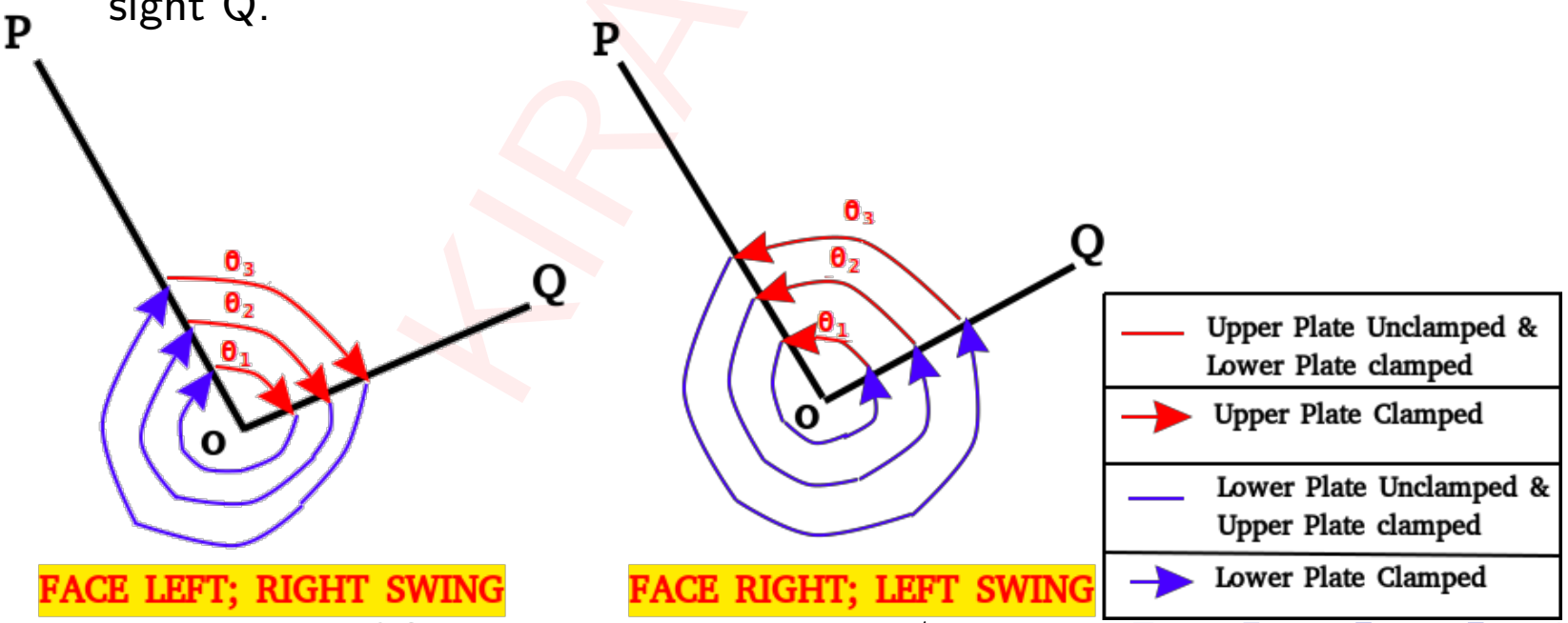
Applications of Theodolite

(i) Measurement of Horizontal Angles:

1. Repetition Method

Procedure: (Contd...)

- Release the upper clamp and turn the instrument clock-wise (swing right) towards Q. Clamp the upper clamp and bisect 'Q' accurately with the upper tangent screw. Note the readings of verniers 'A' and 'B' to get the values of the angle POQ.
- Release the lower clamp and turn the telescope clockwise to sight P again. Release the upper clamp, turn the telescope clockwise and sight Q.



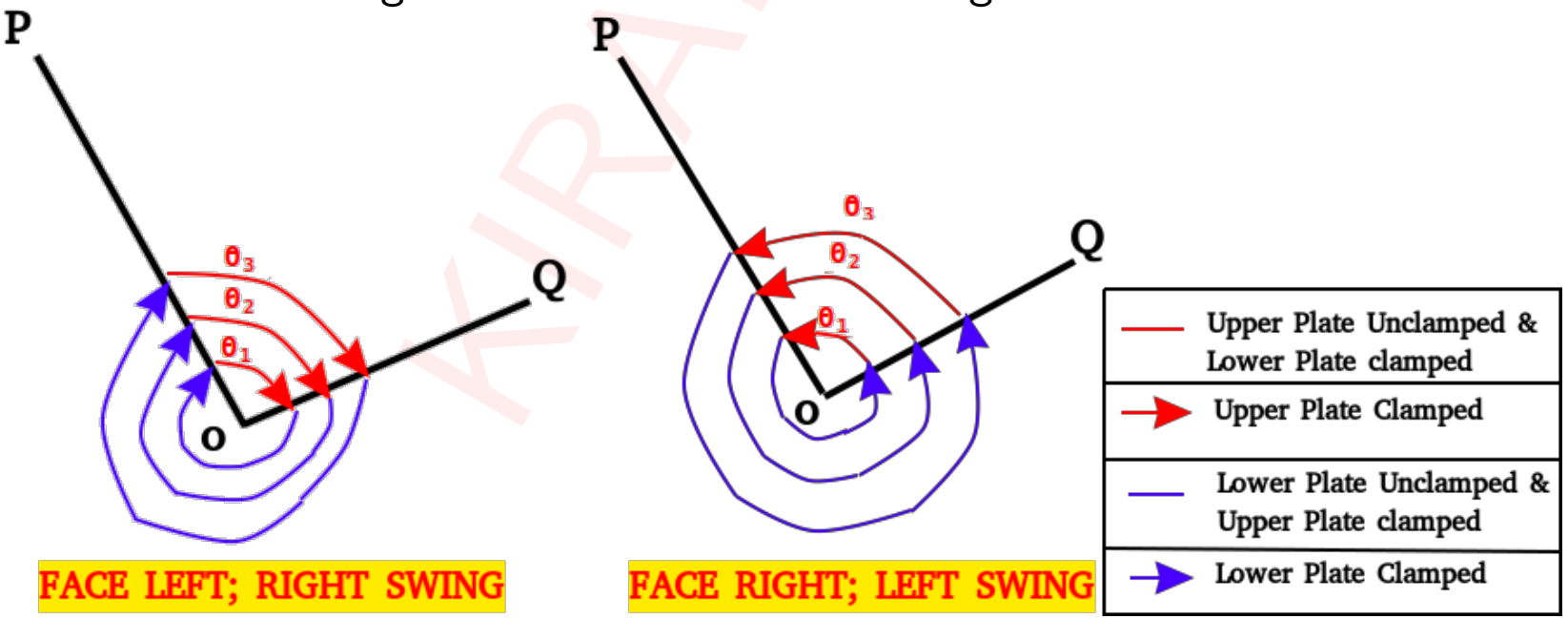
Applications of Theodolite

(i) Measurement of Horizontal Angles:

1. Repetition Method

Procedure: (Contd...)

- Repeat the process until the angle is measured 3 times. The Final Horizontal circle reading $= \theta_1 + \theta_2 + \theta_3$
- The mean angle with Face Left $= (\frac{Final\ \ Horizontal\ \ Circle\ \ Reading}{3})$.
- Change face and make similar observations by Left swing.
- The average horizontal angle is then obtained by taking the average of the two angles with face left and face right.



Applications of Theodolite

(i) Measurement of Horizontal Angles:

1. Repetition Method

A sample observation table:

Instrument At	Sighted to	Face : Left							Swing : Right					Face : Right							Swing : Right				Average Horizontal Angle		
		A			B		Mean			No. of Repetitions	Horizontal Angle			A			B		Mean			No. of Repetitions	Horizontal Angle					
		°	′	″	′	″	°	′	″		°	′	″	°	′	″	′	″	°	′	″		°	′	″	°	′	″
Q	P	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0							
	R	52	41	20	41	20	52	41	20	1				52	41	40	41	40	52	41	40	1						
	R	158	04	40	04	40	158	04	40	3	52	41	33	158	04	40	04	40	158	04	40	3	52	41	33	52	41	33

Applications of Theodolite

(i) Measurement of Horizontal Angles:

1. Repetition Method

Errors eliminated by this method:

- Errors due to eccentricity of verniers are eliminated by reading both verniers.
- Errors due to inadjustments of line of collimation and trunnion axis are eliminated by taking both face readings.
- Errors due to inaccurate graduations in horizontal circle are also eliminated by taking readings at different parts of the circle.
- Errors due to inaccurate bisection of object, eccentric centring etc. are eliminated due to multiple sightings of objects.

Errors which cannot be eliminated by this method:

- Errors due to non-verticality of vertical axis.
- Errors due to centering (slip and displacement of station signals).

Applications of Theodolite

(i) Measurement of Horizontal Angles:

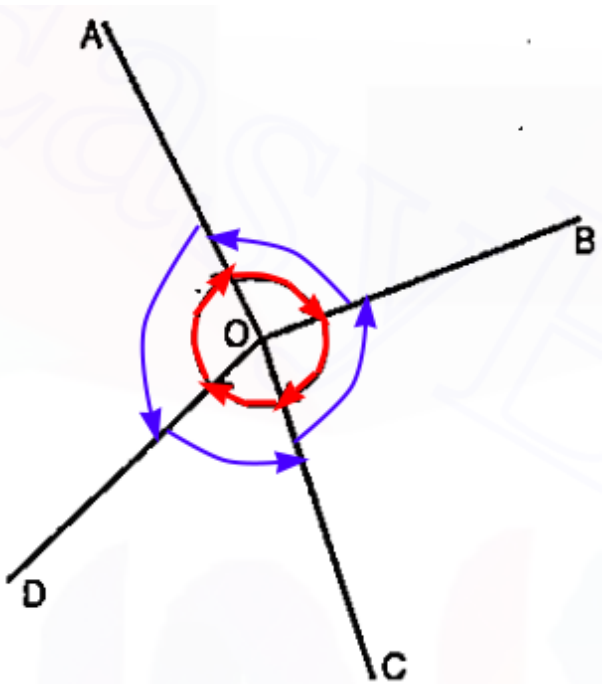
2. Reiteration Method (or Direction Method)
   - used if several angles are required to be measured at the same station.
   - here, different angles are measured successively and the horizon is closed too (i.e., the angle to the first station is measured after the last station).
   - Upon closing the horizon, the last reading of the vernier for the first station should match the first reading to the same station. If not, the error must be equally distributed among the measured angles.

Applications of Theodolite

(i) Measurement of Horizontal Angles:

2. Reiteration Method (or Direction Method)
Procedure:

- Set the instrument over 'O' and level it. Now set the Vernier to zero and bisect point A accurately.
- At **Face Left**, loosen the upper clamp and turn the Telescope clockwise (**swing right**) to point B. Bisect B by using the upper tangent screw. Read both the Verniers, the mean of the Verniers will give the ∠AOB.
- Similarly, bisect successively C, D and finally A, thus closing the circle. Read both the Verniers at each bisection.
- Repeat the steps in **Face Right** from A and **swing left** to sight D, C, B and back to A . The average of angles measured with Face Left and Face Right is then computed.



Applications of Theodolite

(i) Measurement of Horizontal Angles:

2. Reiteration Method (or Direction Method)

A sample observation table:

Instrument at	Sighted to	Face : Left								Swing : Right			Face : Right								Swing : Left			Average Horizontal Angle		
		A			B		Mean			Horizontal Angle			A			B		Mean			Horizontal Angle					
		°	′	″	′	″	°	′	″	°	′	″	°	′	″	′	″	°	′	″	°	′	″	°	′	″
O	A	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0						
	B	54	31	20	31	20	54	31	20	AOB 54	31	20	54	31	40	31	40	54	31	40	54	31	40	54	31	30
	C	102	25	40	25	40	102	25	40	BOC 47	54	20	102	26	00	26	00	102	26	00	47	54	20	47	54	20
	D	239	49	40	49	40	239	40	40	COD 137	24	00	239	49	49	49	40	239	49	40	137	23	40	137	23	50
	A	360	0	0	0	0	360	0	0	DOA 120	10	20	360	0	0	0	0	360	0	0	120	10	20	120	10	20

Applications of Theodolite

(i) Measurement of Horizontal Angles:

1. Reiteration Method (or Direction Method)

Errors eliminated by this method:

- Errors due to eccentricity of verniers are eliminated by taking both vernier readings.
- Errors due to inadjustments of line of collimation and trunnion axis are eliminated by taking both face readings.
- Errors due to inaccurate graduations in horizontal circle are also eliminated by taking readings at different parts of the circle.
- Eccentricity of vertical axis is also eliminated.

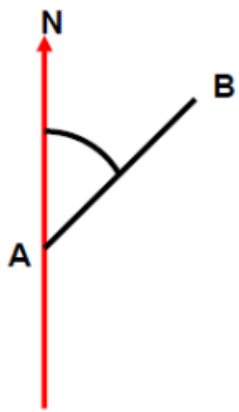
Errors which cannot be eliminated by this method:

- Errors due to non-verticality of vertical axis.
- Errors due to centering (slip and displacement of station signals).

Applications of Theodolite

(ii) Measurement of Magnetic Bearing of a Line:

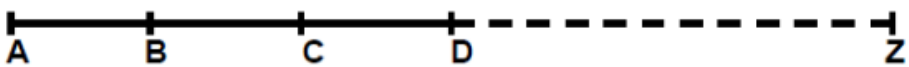
- Setup the instrument over A and level it accurately. The Theodolite shall be provided with a tubular compass or trough compass.
- Set the Horizontal circle vernier to zero.
- Release the magnetic needle and loosen the lower clamp. Rotate the instrument till magnetic needle points exactly to the North.
- Clamp the lower clamp with the help of lower tangent screw. At this stage the line of sight will be along the magnetic meridian.
- Now loose the upper clamp and point the telescope towards B. With the help of upper tangent screw, bisect B accurately and read both the verniers. The mean of the two readings will be recorded as magnetic bearing of line. Change the face of the instrument and repeat the procedure.
- Mean of the two values will give the correct bearing of the line AB.



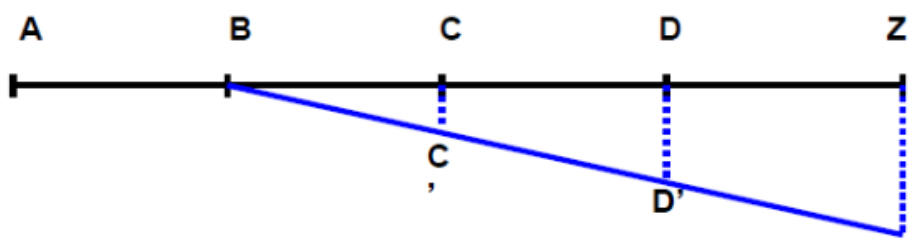
Applications of Theodolite

(iii) Prolongation of a straight line:

- **1st Method:** Set the instrument at A and sight B accurately. Establish a point C in the line of sight AB produced. Now shift the instrument to B and sight C. Establish the point D along the line of sight BC produced. Repeat the process.



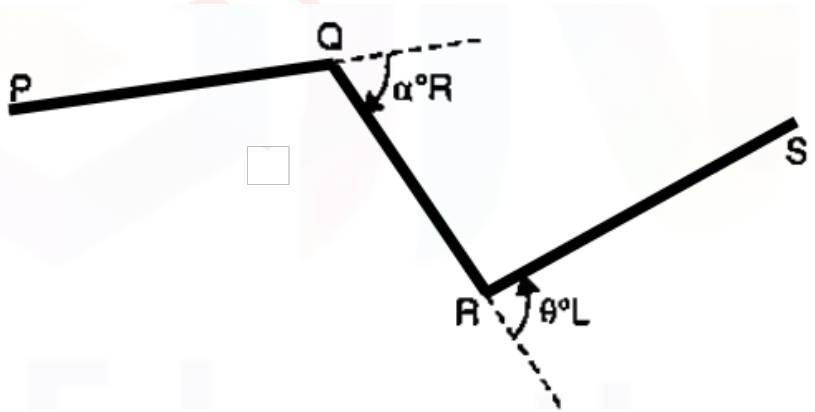
- **2nd Method:** Set the instrument at B; backsight A; transit the telescope and establish a point C in the line of sight. Similarly shift the instrument to C and backsight B; transit the Theodolite to establish point D. Repeat the process.
  Note: If the instrument is in permanent adjustment, points B, C, D, ... will be in the straight line. Otherwise, the points established shall be C', D',... which shall not be in straight line.



Applications of Theodolite

(iv) Measurement of Deflection Angles:

- Deflection angle refers to the angle which a survey line makes with the prolongation of the preceding line. Range from 0-180^0.
- It is designated as Left(L) or Right(R), depending on whether the angle is measured anti-clockwise or clockwise.
- Here, the prolongation of line is performed as above and the horizontal angle is measured from this to the adjacent surveyline using the instrument.



THANK YOU!!!